CMHC File No._____

AN EVALUATION OF THE CMHC #2 COMPUTER PROGRAM.

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Prepared for

The Technical Research Division

Policy Development & Research Sector

of

Canada Mortgage and Housing Corporation

by

Saskatchewan Research Council

May 1982

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This project was partly funded by the CMHC, but the views expressed are the personal views of the authors and no responsibility for them should be attributed to the Corporation.

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1. INTRODUCTION

This report is an evaluation of a computer program now being developed by Canada Mortgage and Housing Corporation, through its Technical Research Division.

The computer program is known as CMHC #2, and is described in a report prepared by GasTops Ltd. (1). Its purpose is to aid the development of new energy-efficient housing at the design stage, and it is directed primarily at single residential units. The program can be divided into two main parts: the first consists of a space heating analysis of a specified residential unit; the second consists of a cost-effectiveness analysis of various ways of upgrading the energy-efficiency of the basic structure - the options being listed in order of cost-effectiveness.

The evaluation can be divided into three components:

- A consideration of the various technical factors built into the program,
- A consideration of the design and objectives of the program,
- A consideration of how the program would be applied, and who would use it.

The evaluation was conducted over the period July 1981 to February 1982. During this period the computer program was being progressively modified and improved - either as a result of ongoing work in CMHC or in response to the findings of this evaluation, which were conveyed to CMHC in the form of three interim reports. This final report is a compilation of the interim reports, and it should be understood that many of the comments may now be out of date, by virtue of the changes that have already been made to the program.

2. BRIEF OUTLINE OF THE PROGRAM

The first part of the program consists of an extensive data entry routine, in which the primary purpose is to specify the house envelope, broken down into the various envelope components, with a specified area and thermal resistance for each. This includes a facility for specifying infiltration/ventilation characteristics and thermostat operation. This first part also gives the operator a choice of cities across Canada, for which the program has a climatic and energy cost data base.

When the data have been entered, the program then proceeds to calculate the heat loss performance of the building envelope, expressed as a building heat loss factor. This calculation is fairly straightforward and can be regarded as a standard procedure for this type of program.

The next step is to calculate the internal heat gains of the structure. These can be divided into two categories: occupant-dependent and passive solar. The occupant-dependent heat gains come from three sources: body heat, appliance usage and domestic hot water usage. These gains vary considerably from one house to another, and there is no realistic way of assigning accurate values. The program therefore uses a data base containing typical heat gain figures, and has a procedure for instructing the operator in the selection of appropriate figures. The passive solar gains are determined from local climatic data and from the sizing, type and location of windows - all of which data were entered in the first stage of the program. Also, at this stage, the operator is required to enter details of any mobile window insulation.

Given the heat loss performance of the building envelope, and a detailed summary of all the factors needed to calculate internal heat gains, it is then possible to calculate the annual space heating requirements of the building. This is where the program encounters a state-of-the-art situation. There are several ways of doing this, ranging from a simple heating degree-day method up to a detailed minute-by-minute analysis of the heat balance of the house. The program offers ten alternative sub-routines at this stage.

This stage of the program finishes with a tabulated output of the calculated energy performance of the house, giving the estimated annual heat balance figures and the estimated annual auxiliary space heating requirements.

The program then enters the second main stage, in which the purpose is to list a wide range of thermal upgrading options in order of cost effectiveness. This relies on an extensive data bank, containing cost estimates for various constructional options. The operator can indicate a ceiling cost for the energy conservation options, and he can also restrict the analysis to certain types of option. When this has been done the program lists the options, their cost-effectiveness and their cost, in order of decreasing cost-effectiveness.

The program has facilities for a repeat analysis and for a final analysis of building envelope performance.

3. EVALUATION PROCEDURE

The CMHC #2 program was made available through the Datacrown link. Cases were run in Saskatoon, through telephone link to the nearest Datacrown terminal in Regina. At certain stages of the work, more than one version of CMHC #2 was available on this link, but all the evaluation work was conducted on the HOUSEN 5 version.

At the beginning of the study a few test cases were run, using data from existing houses with well documented structural design and performance. The output of the CMHC #2 program was then examined in detail. An interim report was submitted in August 1981, outlining some of the more obvious areas of attention in both the program and the GasTops publication (1).

Following this, a number of cases were run on CMHC #2 to determine its limitations - in terms of the configurations it could handle. Supplementary to this, and as part of another project, it was found that the program was not constituted to deal with multiple family units unless considerable ingenuity was used in entering the data. From time to time, ongoing changes in the program made it difficult to run cases. At one point, for example, a test case was rejected as a result of some new window sizing restrictions introduced into the program on a (presumably) test basis.

A second interim report was submitted in September 1981. This considered how the program might be applied and used, together with some remaining technical issues. This was followed, later in September, with some further technical comments that had come to light as the result of further test runs.

Finally, six houses, belonging to staff at Saskatchewan Research Council, were measured and documented, and the relevant data were used to run CMHC #2 cases up to the point where the annual heat balance figures are given. The calculated space heating requirements were then compared with the known requirements of the houses, to provide some commentary of the accuracy of this first part of the program.

4. TECHNICAL EVALUATION

The following points relate to the information given in the GasTops report (1), and all page numbers refer to that report:

4.1 The procedure for dealing with soil insulation effects around a basement (page 10) represents the current state of the art. Nevertheless, it is a crude approximation to a more complicated physical situation, and indicates the need for further research into this mechanism.

4.2 The procedure for dealing with heating options (page 11) is a little restrictive and excludes some interesting or useful alternatives:

- An internal selection of oil, natural gas or electrical heating systems based on cost-effectiveness.
- It is common in some rural areas to have oil-fired space heating and electrical domestic hot water heating.
- Solid fuel burning stoves and fireplaces are popular heating options in some regions.
- There is a growing interest in hybrid systems that use domestic hot water for space heating. The market penetration is not large at the moment, and therefore it would be difficult to justify its inclusion in CMHC #2 for some time.

4.3 The procedure for dealing with passive solar gain (page 12) has been expanded considerably during the period of this evaluation and now includes several alternative sub-routines, giving good coverage of the current state of the art. In one of the interim reports it was suggested that the solar absorption on the building envelope - the sol-air effect - should be taken into account. It is understood that this feature has now been included, and has been found to have a significant effect at certain times of the year. The HOTCAN program (2) on which CMHC #2 is partly based, has been modified recently, and now includes a technique for dealing with shading effects. Some consideration should be given to including this in CMHC #2. This also raises the issue of a more general policy on upgrading CMHC #2, to keep it up with the developing state of the art.

4.4 The procedure for dealing with infiltration (page 15 and Appx. III-2) reflects the current inadequacies in the state of the art. There is a growing body of data on the airtightness of houses across Canada, but the data have been obtained by the pressurization test and do not give an indication of the natural infiltration rate of the houses. The infiltration rate can be approximately derived from airtightness test data, but the resulting figure could be subject to considerable error. Thus, although it is proper to allow for the known effect of volume-to-area ratios (page 15), it should be recognized that this correction is probably insignificant compared with the larger uncertainties built into the estimated infiltration rate.

In a recent paper by Dumont et al (3) it is shown that the natural infiltration rate of a house is influenced by regional variations in building practice, variations in house style and details of the vapour barrier location in the walls. These effects are of the same order of magnitude as the volume-to-area ratio effect, and should therefore be considered. A discussion of these factors, based on the data published by Dumont et al (3), is given in Appendix I.

4.5 The procedure for dealing with air management (page 16 et seq) ignores a number of issues that are now arising around the topic of air quality, and also raises a number of points concerning the application of air heat exchangers.

Currently, the field of residential air quality is in a state of fairly rapid evolution, and is characterized by more unknowns than certainties. Previously, it was assumed that moisture control should be the main element of air management system design. For this, air change rates of 0.3 ach or less were found to be adequate. Recently, the concerns about air quality have centred on pollutants such as radon gas and formaldehyde, and the control of these has tended to supersede moisture control as the main element in air management design. The ideal air change rate is now believed to be somewhere between 0.3 ach and 0.5 ach, with conservationists favouring the former and air quality enthusiasts favouring the latter. There is still not enough hard practical data to support one figure rather than the other. Energy, Mines and Resources appear to favour a 0.5 ach figure, presumably because it is a pretty good safeguard against

the risks of poor air quality. Conversely, there are many who believe that 0.3 ach is adequate. In an earlier interim report, as part of this evaluation, a figure of 1/3 ach was recommended as a basis for air management design, but in view of the growing emphasis on air quality it might be advisable for CMHC to adopt a slightly higher figure. An air change rate of 0.4 would be a fairly good design compromise.

To apply this criterion in CMHC #2, it is recommended that a ventilation system be included whenever the natural infiltration rate of the structure is likely to fall below 0.4 ach. The ventilation system should then be sized so that the total air movement rate through the building - made up of infiltration and ventilation - should be 0.4 ach or higher.

The ventilation system should be offered in two forms: the first being a simple system without an air heat exchanger, and the second should be a more elaborate design, incorporating a heat exchanger. The simple system consists essentially of an insulated air duct feeding exterior air into the return-air side of the furnace, and has an estimated cost of about $150. The choice between the simple or elaborate ventilation systems should be made on the basis of cost effectiveness.

Regarding the heat exchanger units: at least one design (the Lossnay) has the ability to recycle house moisture, and therefore it may not provide adequate moisture control.

Some heat exchangers can be installed for as little as $800, using 1981 prairie prices. It might be appropriate to build some cost variations into CMHC #2, which appears to operate with an assumed flat rate of $1200.

Recent monitoring data from Saskatoon's energy showcase indicates that many of the heat exchangers in this project have been incorrectly set up and balanced, and are operating below their rated efficiency. This can be attributed to lack of experience of the sub-trades, and possibly to inherent faults in the units themselves. Whatever the origin of the efficiency shortfall, it

should be interpreted as being representative of the current state of the art in heat exchanger installation. It is therefore recommended that CMHC #2 adopt a lower heat recovery factor. It is difficult to be absolutely specific about the best figure, but 60% is probably better than 70%, and is therefore recommended.

If the airtightness of a house is gradually improved, there comes a point where it needs a separate air supply for combustion units, in addition to any ventilation requirements. The incremental cost is small, provided that the supply does not include such things as a sealed furnace room. However, the combustion air supply, if properly designed and installed, will reduce the furnace loading on the house envelope and will thereby reduce the natural infiltration rate. The understanding of this effect is still far from quantitative, and it is something that might be considered for inclusion in CMHC #2 at some later date.

4.6 Several points need to be made about the procedure for presenting energy-conservation options in terms of cost effectiveness:

- Cost effectiveness is determined purely in terms of the reduction in heat loss (page 18). This does not give a true assessment of the actual energy savings, since an energy conservation option may have a secondary energy saving effect on the furnace (reduced fuel usage means reduced flue losses).
- It is not always advisable to adopt energy conservation features on the basis of cost effectiveness; there may be other considerations to take into account. For example, it might be found advisable, on the basis of cost effectiveness, to add 2" of styrofoam to the exterior of a basement wall. Practical factors might dictate that this should only be done along with similar work on the stud frame. In the design of an energy efficient house there are interactions between the various components, some of which we are only now beginning to appreciate. Some of these interactions may be dictated by simple factors of constructional design, while others may arise from more complicated considerations, such as the avoidance of moisture problems in the long term. As a result of such considerations, it is later recommended that this part of the program be based on a packaged design approach.

- The thermal performance of the house can be improved in three basic ways: by reducing the envelope losses, by increasing the passive solar gain or by adopting a more efficient furnace. The method used in CMHC #2 to calculate cost effectiveness (page 18) is suited only to the envelope losses. The only reliable way of comparing measures of different types is to calculate their effect on the annual fuel bill. This is recommended as a better basis for assessing and comparing cost effectiveness.
- The relative cost effectiveness of two measures often depends on the order in which they are done. Under certain circumstances this might affect the validity of the ranking procedure. This is another argument in favour of using a package design approach.

4.7 The costs of materials and labour may vary appreciably from one region of Canada to another. Accordingly, it may be necessary to set up a cost data base for each region. This applies to the data given in Appendix II-6 and Appendix III generally.

The cost data base in this program can serve as a valuable reference on costs,provided it can be kept up to date. For example, some of the costs in Appendix III, relating to doors and windows, appear to be about a year out of date. Over the last year or so there has been a significant shift in the relative costs of various door designs and window designs; a triple glazed window now costs little more than a double glazed one in Saskatchewan. Also, the cost differential between solid core wood doors and thermal is now very small.

Clearly, it will take a major commitment of effort to keep the cost data bases current, especially if regional factors also have to be taken into account.

4.8 The design options (Appendix III) will need to extended to include regional factors and correct some omissions:

- It is not standard practice in Saskatchewan to use 19 mm fibreboard sheathing.
- The ceiling options should include a vaulted design.
- Window options need to be extended to include all common types and composites such as fixed-casement designs.

- Door options should be extended to cover patio types and other glass designs. South facing doors with glass inserts can be treated as part of the passive solar design. There is nothing in CMHC #2 to prevent such doors being entered as windows, but this trick needs to be explained to users.

4.9 The situation regarding furnaces has changed significantly since the first interim report on this study. Experiences with combustion furnaces in energy-efficient houses have revealed a number of unsuspected factors. The following is a list of some of the current concerns:

- There are indications that the new generations of high-efficiency furnaces may have a lower seasonal efficiency than anticipated.
- Automatic flue dampers are not as effective as anticipated, partly because of poor sealing around the damper, but usually because of the short-circuiting effect of the domestic hot water heater flue.
- Furnace rooms are not the energy savers that they were expected to be, and may, in fact, be responsible for energy losses.
- The seasonal efficiency of a furnace in an airtight house, with or without its own combustion air supply, needs further investigation.
- The safety margin appears to be reduced on furnaces in energy efficient houses. Such houses impose tighter design constraints on the furnace units. Any significant departure from proper design may create problems. In short, the furnace design may be dominated by factors other than cost effectiveness.

Currently, therefore, it would be unwise to get too specific about the techniques for dealing with furnace efficiencies in CMHC #2. It is anticipated that the research on furnace problems will be stepped up in the immediate future, and it is possible that many of the problems will be quantified and solved within a year or two. In the meantime, CMHC #2 has responded to the state of the art by adopting slightly reduced furnace seasonal efficiencies. This is, perhaps, the best course to take for the time being.

The following comments are based on test runs conducted in August 1981, and relate to specific parts of the computer printout.

4.10 The program lists twelve sites for which there are climatic and fuel cost data. This is probably adequate for the time being, but will need to be extended if the program becomes available nationally. The printout of sites might also include the site latitude, for the information of the user.

4.11 The program lists six house types, consisting basically of three design options, each having the further option of basement or no basement. This range should be extended to give better coverage of common design options. The following three are suggested:

- Slab-on-grade foundation.
- Unheated crawl space foundation.
- Mixed basement and unheated crawl space, as is found in some split-level designs.

Appendix II gives a recommended way of dealing with these options.

4.12 As explained earlier, the program should offer more alternatives in the energy source section, to cover common situations such as oil space heating with electrical DHW heating.

4.13 The ceiling area and the plan area may not always be identical (eg. a cathedral ceiling has a larger area). In the earlier version of the program it appeared that the program used ceiling area as plan area when calculating infiltration factor corrections.

4.14 Greater flexibility is needed for entry of wall areas and R-values. It is suggested that this be made open ended, so that the operator can enter the wall specifications broken down into several components. This will be particularly useful in dealing with exterior walls that adjoin greenhouses, partly heated garages etc.

4.15 Greater flexibility is needed in entering window specifications. For example, the windows on one wall may have different glazings

and therefore different R-values. Basement windows generally tend to have a lower R-value than the main house windows. Also, the user should be encouraged to enter glass-insert doors in the window section, particularly where such doors are located on the south of the house and make up a part of the passive solar design. In such a case, allowance should be made for the possibility of having different R-values in the main windows and in the doors. Another example of varying R-value can occur in composite windows, which may have a triple glazed fixed section and a double glazed casement section.

4.16 Some compensation is needed for exterior doors that open into a garage or greenhouse or other sheltered area, but the effect is probably too small to justify amendment.

4.17 The program identifies three types of exposed floor situation: overhang, floor above garage and crawl space. Each of these has to be treated differently. The overhang connects directly to exterior conditions, the floor above a garage has an exterior temperature that is modified by the garage, the crawl space R-value is modified by soil thermal effect. Since the three situations are grouped under the same heading it is unlikely that each type is given the appropriate treatment. It is recommended that this be expanded to allow individual treatment.

4.18 Some clarification or re-wording is needed for the entries dealing with below-grade foundation walls. This can be entered in two parts, labelled "below grade foundation wall" and "uninsulated below grade foundation wall". It is not clear whether the first label refers to all the foundation wall or merely the insulated part.

4.19 The foundation wall is assumed to be concrete, and the program makes a correction for the thermal resistance of the concrete. This introduces inaccuracies when a pressure-treated wood foundation is entered. It is recommended that provision be made for entering PWF foundations.

4.20 The volume of heated space is specified as part of the air infiltration routine. Some confusion might arise here if the garage is heated (a common situation in Quebec). It is recommended that the text be changed to stipulate the air space within the vapour barrier envelope.

4.21 In the earlier version of the program the user was given no guidance on air infiltration rates. This has been rectified in the latest version.

4.22 The user is required to give the weighted average thermostat setting, in both the original and the latest versions of the program. Some users will not know how to do this. A simple analysis is given in Appendix III.

4.23 The tabulated heat losses of the building shell appear to be satisfactory, allowing for some of the state-of-the-art information that is used in some of the calculations. The program corrects the gross wall area by subtracting the areas of windows and doors. This procedure may often be invalid; basement windows, and sometimes part of the door area, should be subtracted from the area of the foundation wall. The data entry section does not allow this distinction.

4.24 The program gives an output labelled passive solar design considerations, in which the actual window areas are compared with optimum areas. This is followed by a sub-routine that allows changes to the house specifications. This appears to be the only facility for refining the passive solar design of the house. It would be better to include this in the later part of the program, where the options are listed in order of decreasing cost effectiveness. The cost effectiveness of the passive solar design could then be compared against competing options.

4.25 The program prints out a table of daily energy use for appliances and DHW heating. Two aspects of this table were queried in the first interim report:

- It was not clear if the appliance usage included such things as car plug-ins or externally-vented dryers, which give no internal heat gain. This point is covered with a brief explanation in the latest version of the program.

- The given DHW energy use figures are actual 'delivered heat' and not 'consumed energy'. The two are identical for electrical heating, but differ for gas heating because of the efficiency of the DHW combustion unit.

4.26 A point of nomenclature was identified in the original program version: that the term 'purchased energy' was an incorrect heading in the thermal energy analysis summary. This wording has now been altered to read 'energy required by house' in the latest program version.

4.27 The thermal energy analysis summary contains a table labelled 'cost benefit analysis'. In the recent version this label has been retained and several new items of data have been included. The meaning of the table would be more clear if the title showed that it related only to furnace options.

The following points relate to the second part of the program printout, which deals with the cost-effectiveness ranking of various upgrading options:

4.28 Generally, it is difficult to understand the information given in this table. Even after an hour or so of examination, it was still unclear what the correct upgrading decision should be, based on the information given in the table.

4.29 The options relate specifically to envelope losses, though furnace options are considered at various junctures in the listing. The value of the table is slightly diminished by the fact that it does not include the options of passive solar design and DHW heating systems. Also, windows tend to be upgraded en bloc, when it might be more appropriate to upgrade the non-passive units and leave the passive units alone.

4.30 In certain modes of use , there appear to be some 'bugs' in this part of the program:

- The first data line in the table was especially misleading in the original program version, but appears to have been rectified.

- In some cases the program will print out the following message several times: "No legitimate comparison could be made between the envelope options and furnace #4". It is not clear what this means, or why it needs to be repeated as many as nine times.

- Occasionally, the program goes beyond the maximum dollar investment stipulated by the user.

- If the user specifies an investment greater than can be accommodated by all the programmed options, the program goes into a loop that repeatedly prints out a final statement.

- On occasion, the listing of a furnace #4 type in the Summary Listing causes the program to go into a loop.

- The program does not appear to update any changes made to the house specifications. For example: the user may run through a case and end up with an upgraded house, for which the program gives a total annual heat loss and cost analysis. It may be desirable to relocate this upgraded design to some new climatic area and look at the possibility of further upgrading. In such a case the program retains the upgraded options but it does not retain the running costs that go with them.

- The program does not have a cross-checking mechanism when it introduces a heat exchanger option. It will list an air to air heat exchanger, and will increment the running total cost, even though a heat exchanger was specified as part of the original house design.

- The program may ignore the originally-specified air change rate and impose a newer, but higher, air change rate with an associated cost increment.

- The program allows the user to modify any previous upgrading options. Thus, the user can downgrade an option either totally or partly. When this is done, the program does not make the proper corresponding corrections to the total running costs (Thermal Options) or Capital Cost Premium (Summary Table). It may actually give a negative total annual heating cost.

- There appears to be some discrepancy in the incremental costs of some of the listed thermal options. The costs do not apply to Saskatchewan. It is suspected that this may be due to the use of a single cost data base for all locations, as a temporary measure during the development of the program.

5 PROGRAM APPLICATION

5.1 Will the big builders use it?

Possibly, depending on the credibility and ease of access of the program, but the usage is unlikely to be intensive. Big builders will use the program in one of two ways: either in designing a new range of options (energy conserving) for their new standard line, or in designing a customized variation at the request of a customer. The first way will involve the builder in intensive use of the program for two to three days, when he is setting up a new line of house designs. This may happen only once every two or three years. The second way will involve intermittent use of the program, possibly at a low level of about 10 cases per builder per year.

Some big builders offer energy conservation options on their standard lines already, and appear to have a set procedure for selecting, designing and costing these options. CMHC #2 would probably give them a more streamlined design process, but the builder would probably reject the program if its cost data disagreed with his own assessment. Big builder response will depend on the credibility of the program and the way it is promoted.

5.2 Will the custom builders use it?

Most probably, provided that it is easily accessible. A large number of energy efficient houses in the Saskatoon area have got built as a result of home owner initiatives. The home owner decides to build an energy-efficient house and and starts by shopping around for a suitable design. More often than not, he will take this design to the custom builder to have it rendered into an energy-efficient design. At this point, the home owner usually has some fixed ideas about the energy conserving features of the house, and he would work with the custom builder to refine the design options. This is where CMHC #2 would be of value. Note that some custom builders are now listing computer design facilities as part of their sales promotion effort. Also note that there has been a sharp decline in the number of small custom builders in practice, mostly as a result of the general problems now being experienced in the building industry.

5.3 Will the home owner use it?

Some home owners, having made the decision to build an energy-efficient house, find that the building industry is reluctant to give them what they want, or that the costs are too high. They may decide to act as their own general contractors (note that this appears to be a growing factor, perhaps in reaction to rising house financing costs). A significant proportion of energy-efficient houses get built this way - in fact, this is how many of the small energy-efficient builders have gone into business in the Saskatoon area. CMHC #2 should be made available to this sector, where it will probably meet with more response than in other sectors.

5.4 Will architects and designers use it?

A small proportion of home owners use architects or designers to develop a customized energy-efficient design. Experience at SRC over the last two years has shown that such designs tend to be exotic and complicated, with energy conservation being just one more selling feature in the overall design. Generally, such designs tend to be too complicated to be handled by CMHC #2.

5.5 An estimate of usage.

The proper way to estimate the potential usage is to conduct market studies, and it is recommended that this be done before CMHC #2 is made generally available. The results of the market study might indicate a more appropriate format for the program, in addition to identifying the target uses.

In the absence of market study data, it is estimated that somewhere between 10% and 20% of all possible users (builders, owners, architects etc.) will actually use the program. Over the last three years in Saskatchewan, somewhere around 200 to 500 houses have been built to reasonable standards of energy efficiency. This works out to about 100 per year, of which about 20 might have been run through CMHC #2 had it been available at the time. Taking into account the level of energy efficient construction

starts across Canada, and the current state of the building industry, it is estimated that CMHC #2 might experience a usage rate of about 400 cases per year, rising to 1,000 per year or more if the status of the industry improves. One factor that should be taken into account is typified by Saskatchewan's Home Energy Loan Program. It is quite likely that, over the next few years, most of the energy-efficient housing starts in Saskatchewan will conform to the HELP design requirements, and will therefore not require the aid of CMHC #2 or similar programs. Parallel initiatives in other provinces may have a similar or greater effect.

5.6 How should the program be implemented?

The average user will probably run less than 5 cases per year through the program. Few users will have the basic skills needed to operate the program, and the low frequency of use will not give them much opportunity to develop these skills. Therefore, they would need the services of a skilled terminal operator, who is familiar with the 'ins and outs' of the program. The Datacrown network might be suitable, provided that a skilled operator is available. Alternatively, the program could be leased or sold to some of the small private companies who provide an operator service.

Some builders might wish to operate the program on their own desk top computer facilities. The big builders, in particular, are venturing into computer technology, and have a big enough operation to provide the required infrastructure. This approach could work out quite well, given the right kind of promotion and an efficient mechanism for updating all data bases. The cost information alone would be of considerable value to many builders, provided it were always kept up to date.

6. PROGRAM DESIGN

6.1 Data Input.

The prospective user of the program will first have to assemble all the required input data pertaining to his house design. In this he will need some guidance, so that the data are precisely what the computer needs (ie. gross wall areas rather than net areas). The best way to achieve this is to provide users with a data entry form, arranged something like the annual income tax forms, with small boxes for data and plenty of explanation and guidance. If this is done correctly, it allows a considerable reduction in the running time for each case, since all the data can be loaded sequentially into the computer from the data entry form. The data would then be tagged in sequence, as it is loaded, and there would be no need for the lengthy and time-consuming data entry routine. In short, the data should be sorted out by the user before he brings it to the computer.

6.2 The energy analysis stage.

This first stage of the computation is an adaptation of the NRC HOTCAN program. It incorporates several improvements over the HOTCAN design, notably a wide range of alternative sub-routines for dealing with passive solar gains, and a more detailed and explanatory way of modelling the various important parameters of the house energy balance. The various sub-routines built into the program are representative of the state of the art. Generally, this part of the program is as good as most of its competitors, and better than some.

The main disadvantage of this part of the program is that it can accommodate only a narrow range of house design options. It is basically limited to single detached units, when, with little modification, it could be adapted to duplexes, row and apartment units. In single detached units it does not have the flexibility for handling some fairly common design variations, such as split levels with combined basements and crawl spaces, or even simple wood-frame units on an unheated crawl space. This latter option can be entered, but there is good reason to doubt the procedure for treating heat losses through the crawl space.

6.3 The cost-effectiveness analysis.

This section requires a fairly large data base, covering the costs of a wide range of thermal options. Currently the data base appears to be restricted to costs pertaining to Ontario, but when the program is applied nationally, the data base will have to cover regional cost variations. If the program is to establish and sustain its credibility, then this data base has to be kept up to date. This will involve a considerable long-term commitment on the part of CMHC, and it might be advisable to write a supplementary computer program to handle the basic cost information and reduction. The data base will be of considerable value in its own right, and some thought should be given to ways of making the cost information available to the building industry.

The cost of a particular energy conservation measure will vary from one town to the next, from one builder to the next and from one week to the next. A cost variation of about 10% would not be unusual, yet a variation of this magnitude would sometimes have a significant effect on the position of the measure in the ranking of cost effectiveness. It would be unrealistic to try to compensate for variations in cost, but it might be wise to point out, to potential users, that cost variations will occur, and will affect the relative ranking of the measures to some degree.

In the authors' opinion, the main weakness of this part of the program lies in the multiplicity of thermal options. The options are ranked in decreasing order of cost effectiveness, and other requirements tend to be ignored. In effect, the program treats the house as an assembly of non-interacting parts, each of which can be modified irrespective of the others. Some factors are built into the program to compensate for this, such as the procedures for introducing furnace changes and heat exchangers, but these are not a total solution of the problem. Some of the options interact through simple structural factors, such as the application of rigid insulation to the exterior of the basement wall, and the discontinuity it creates at the junction with the stud frame. The main interactions occur through the moisture level of the house, which is affected by the vapour barrier construction, furnace type, combustion air supply, ventilation system, window design and climate.

To overcome the possibility of undesirable interactions, it is recommended that the program deal with a small number of packaged design options rather than the large number of individual thermal options. The following package options are suggested:

- 1975 Standard, as a base for cost purposes.
- The 'Measures' (4)
- The Target design recommended by SRC (5)
- The Super Energy-Efficient design, corresponding to the levels adopted in the Saskatoon Energy Showcase.

Some individual design variations should be accommodated for each of these four basic packages, but it is important that each package consists of a well-designed entity in which all the interactions have been thought out, and all potential problems avoided.

The advantages of this approach are:

- The program recommendations are more easily comprehended by the user.
- The data base is more compact, and therefore more suited to desk-top computer applications and regular updating.
- The options consist of well thought out packages, in which the risk of long term problems is reduced.
- The user is spared the effort of translating the options into a specific design, since most of the design details should be worked out as part of the package design.
- It allows CMHC to interface CMHC #2 with its in-house target designs and update the options quickly according to the developing state of knowledge.

6.4 Can the program be extended to include retrofit?

This can be done, but it will require a considerable modification of the program, to the point where its application to new housing might be impaired by over complexity. In existing housing the house specification is far mor complex; it has to take into account different levels of insulation in different walls, basements that are insulated half-way down the wall, or half-way around the wall, or some combination of both. Infiltration levels can be large, and the source of infiltration may vary significantly from one house to another. All this can be taken

into account, but it would require a specially designed program. At the same time, the range of retrofit options cannot always be assessed on the basis of cost alone, and the costs themselves may vary considerably according to the specific problems of the house. It can be done, but it will require a tremendous effort.

7. TESTING THE PROGRAM

Six test cases have been run on the program, using data pertaining to six existing houses in Saskatoon. The houses are occupied by SRC staff and their families. Each of the six staff were required to submit fuel bills for a period of at least one year, together with a detailed summary of thermal envelope of the house, level of occupancy, type of furnace etc. All six houses were heated by natural gas, for space heating and domestic hot water. Five of the houses were fairly standard bungalow-with-basement designs and one was a bi-level.

The fuel bills were analysed to determine the amount of fuel consumed for space heating. The rate of natural gas consumption during the summer months was assumed to represent the average annual rate of gas consumption for domestic hot water heating, and this calculated figure was then used to derive the space heating consumption from the fuel bills.

The recorded period of the fuel consumption varied from house to house. The corresponding heating degree-day figure was obtained for the corresponding one-year period for each house, and this was then used to correct the actual consumption to an average climatic condition. This was done by pro-rating the actual consumption according to the ratio of actual heating degree-days and long-term average heating degree days. The purpose of this correction was to reduce the house consumption data to the climatic situation that is built into CMHC #2, for the basis of comparison.

The house envelope data, and other information supplied by the owners, were run as cases on CMHC #2, using the HOUSEN 5 variation in the form in which it existed in February and March 1982. The program gives a predicted auxiliary space heating requirement for the house. This was corrected to actual natural gas consumption using an assumed seasonal furnace efficiency of 62% - this being the figure used in CMHC #2 for the type of furnace in use in the test houses.

The details of the houses, and a comparison of actual and predicted fuel consumptions, are given in Table I. The discrepancy between the actual and predicted performance is very large, and shows that CMHC #2 consistently predicts a higher than actual space heating fuel consumption.

The reasons for the discrepancy are not obvious. Part of it is due to inaccuracies in the house data, as entered into the program, and part is due to inherent inaccuracies in the computer program itself. The house data have been assembled by six different people, each with some scientific background. They were not required to go to any extreme lengths in preparing the building envelope specifications and other information. Therefore, the data itself can be considered a source of error. However, it is unlikely that individual data errors can account for the considerable discrepancies in Table I.

It is concluded that CMHC #2 may contain significantly large errors, and, by inspection of the program's workings, these errors are probably a reflection of the state of the art rather than a result of inherent errors in the program. If this assumption is correct, that the errors arise from the state of the art, then similar errors can be expected to occur in other programs of this type, which have not taken as much trouble to incorporate the state of the art. When one examines other programs, such as HOTCAN, which is closely related to CMHC #2, one notes that they have not been given a rigorous test against houses with known thermal performance - except in a fairly narrow range of houses with high levels of energy efficiency.

It is recommended that this test be repeated, to determine the accuracies of CMHC #2 and similar programs. To give the programs a fair test it will be necessary to monitor the space heat consumption of the test houses fairly precisely over a one-year period; and the thermal parameters of the houses, including the occupancy patterns, will need to be established with equal precision. In the meantime, the results of the tests, described above, cannot be considered definitive enough to justify any far reaching comments about the accuracy of the program. They indicate that a problem may exist, and that is the fairest interpretation that can be placed upon them.

House age	Constr. rating (*)	Plan area	Style	Occup.	Annual Space Heating (**)			Error
					Actual	Corrected	CMHC #2	
1959	SFA	1167 ft^2	Bung & Base	3	80.6	97	162	+67%
1957	SFA	1050	Bung & Base	4	110.8	127	244	+92%
1963	Meas	1050	Bung & Base	2	83.8	99	166	+68%
1976	CHIP	1497	Bung & Base	3	187.3	216	360	+67%
1979	Meas	990	Bi-Level	2	80.9	94	107	+14%
19--	CHIP	1400	Bung & Base		152.3	156	186	+19%

* Construction rating gives approximate energy-efficieny level: SFA means standard for age, Meas means approximating to the Measures standard, CHIP means standard for age with some extra attic insulation.

** Space heating is expressed in annual gas consumption in Mcf.

TABLE I Comparison of actual space heating and CMHC #2 calculations for six houses in Saskatoon

8. CONCLUSIONS AND RECOMMENDATIONS

The CMHC #2 program is basically a very good idea that needs further development before being released for general use. The first stage of the program, which is concerned with the thermal analysis of the residential building envelope, is reasonably representative of the state of the art and in some respects is superior to other programs of the same type. Tests against houses with known thermal performance have revealed large discrepancies between theoretical and actual fuel consumption. Some of this can be attributed to inherent errors in the program, which are believed to represent shortcomings in the state of the art, but the tests cannot be considered definitive enough to justify comments on the magnitude of the errors. The first stage of the program will need some development before it can be regarded as suitable for general use. Most of this development relates to the flexibility of the data input routine, which needs to be expanded to accommodate more of the common house design variations.

The second stage of the program gives the user the opportunity to select thermal upgrading options on the basis of cost effectiveness. This is a useful and innovative approach, though it could benefit from further development. This part of the program appears to made up of several interacting sub-routines, and there are some modes of operation that have not yet been totally 'de-bugged'.

The following recommendations are made:

8.1 The handling of air infiltration parameters should be extended to cover state of the art information, including the effects of house type, vapour barrier location and regional construction practices.

8.2 The range of house types should be extended to include slab on grade, combined basement and crawl space, and unheated crawl space. Also, a new routine needs to be introduced for handling the effects of an attached garage.

8.3 The upgrading options should be presented in the form of design packages, covering the full range of energy conservation levels, from 1975 Standard up to Super Energy-Efficient. Detailed variations should be allowed for each package.

8.4 The user should be provided with a well-designed form that allows him to sort out all the required data and organize it on paper before bringing it to the computer. This will eliminate the need for a conversational input stage, and will speed up the operating time.

8.5 Consideration should be given to the value of the cost data that are built into this program. It is believed that a large sector of the building industry would be interested in the cost data, and there might be some merit in making it available through a separate printout routine.

8.6 The accuracy of the program should be investigated more thoroughly by conducting precise comparison tests against a fairly large number of houses (up to 50) with well documented thermal performance parameters.

8.7 Some consideration should be given to the marketing and promotion of this program, as a way of increasing its level of use.

9. REFERENCES

1) GasTops Ltd. & CMHC — Interim Documentation for CMHC-2. The Computer Model for Heating Cost Effectively. CMHC, July 1981.

2) Dumont, R. S., & Hamlin, T. — A Simple Computer Program for Estimating The Space Heating Requirements of Residences. DBR, NRC, Saskatoon, July 1980.

3) Dumont, R.S., Orr, H.W. & Figley, D.A. — Air Tightness Measurements of Detached Houses in the Saskatoon Area. DBR, NRC, Ottawa, Nov. 1981, Report No. 178. ISSN 0701-5232.

4) Associate Committee on the National Building Code — Measures for Energy Conservation in New Buildings 1978. NRC, Ottawa, Report No. NRCC 16574.

5) Eyre, D. — The Target House. A Consideration of Technical, Strategic and Economic Factors. SRC Pub. No. E-825-6-C-81, October 1981 (Confidential).

APPENDIX I

RECOMMENDED TREATMENT OF AIR INFILTRATION RATES

First, it is recommended that the five air change rates (in Appendix III-2 of the GasTops report) be extended to include a sixth, rated at 0.05 acph. The requirements for this rate are the same as for 0.10 acph, but with an extra requirement of inspection and remedial repair. The incremental cost of this can be assumed to be about $100 above the 0.10 acph cost.

The range of infiltration rates should be corrected to bring them more into line with the experimental data od Dumont et al (3). This report deals with the infiltration performance of houses, as determined by the pressurization test. The data do not give any accurate indication of the natural infiltration rates of the tested houses, and it is necessary to use an approximate conversion technique. This consists of taking the air change rate measured at 50 Pascals pressure difference, dividing it by 20 and adding a figure of 0.25 acph to allow for furnace-induced infiltration. For a standard house, using Dumont's average figure of 3.60 acph at 50 Pascals, the natural infiltration rate is therefore estimated to be:

$$\frac{3.60}{20} + 0.25 = 0.43 \text{ acph.}$$

Taking this as an upper limit to the range (for new housing), the figures given in the GasTops report should be corrected as follows:

GasTops acph	Corrected acph
0.70	0.45
0.50	0.32
0.45	0.29
0.25	0.16
0.10	0.10
-	0.05

It must be recognized that this is a very uncertain and inaccurate procedure, reflecting the current lack of information in this area. In time, better data may become available, but for the time being the above corrected figures are at least consistent with the state of the art.

Dumont et al (3) show that house style has a significant effect on infiltration performance. Using Dumont's figures, the following corrections have been derived:

House style	acph multiplier
Bungalow	0.84
Bi-level	0.94
1.5 storey w. basement	1.21
2 storey w. basement	1.22
Split level	1.25

Dumont also shows that infiltration performance can be affected by regional factors, presumably related to regional construction practices. The following regional corrections are therefore recommended, on the basis of Dumont's data:

Saskatoon/Prairie	1.00 multiplier
Central Canada	1.23

Similarly, Dumont shows that the position of the vapour barrier has an effect on the achievable airtightness. The following recommended corrections are based on Dumont's data:

Standard v.b. location	1.00 multiplier
Set-back v.b. location	0.56

To give a worked example: assume a class 2 vapour barrier, with a corrected infiltration level of 0.32 acph, on a bi-level house in Ottawa, with standard vapour barrier location:

Infiltration rate = 0.32 x 0.94 x 1.23 x 1.00 = 0.37 acph.

APPENDIX II

RECOMMENDED EXTENSION OF HOUSE STYLE OPTIONS

It is recommended that the house styles be extended to include:

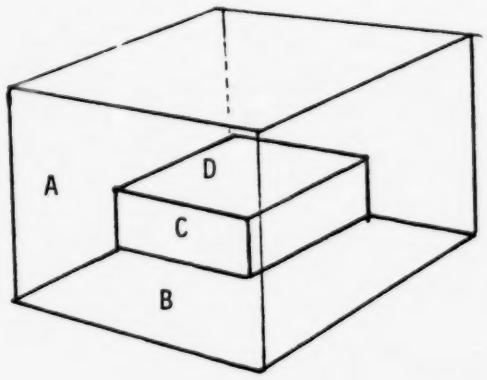
- Slab on grade foundation
- Unheated crawl space foundation
- Mixed basement and unheated crawl space foundation, as is common on some split-level designs.

It is recommended that the data input routine be revised so that the house envelope can be treated in two stages. The first stage would define the wood-frame upper storeys and the second stage would define the foundation configuration. The second stage would consist of a four-way branch, allowing different treatment of each of the four design variations:

- Full basement
- Part basement, part unheated crawl space
- Full unheated crawl space
- Full slab on grade

Note that a heated crawl space is not included, because this generally falls inside the warm envelope of the house, and can be accommodated within the basement specifications.

For the combined basement and crawl space, the program should be able to deal with the following situation:



The basement wall (A) is treated in the normal way, and so is the basement floor (B). A separate routine, allowing for soil effect, will be needed to handle the crawl space side walls (C) and the crawl space floor (D).

For the full unheated crawl space it will be necessary to specify the floor area and the insulation level. A separate routine will then be needed to calculate the effective thermal performance of the crawl space itself. This will depend on soil effect, air movement through the crawl space and insulation around the perimeter wall of the crawl space.

For slab on grade, the main problem will be to assign an effective thermal resistance to the soil under the slab, and to develop a suitable mechanism for dealing with perimeter heat losses from the slab.

As well as the extra foundation options, the program should also be extended to cover attached garages, whether heated, partly heated or unheated. This is a common feature of most new housing. The effect of the garage can be treated in two ways: as modifying the insulation level of the common wall, or as modifying the effective exterior temperature. Currently, SRC assumes that garages have no significant effect on shell heat loss, if they are unheated. This, however, is regarded as being a very unsatisfactory temporary treatment.

It should be noted that, if the above options are included, it will also be necessary to extend the data base on thermal options and associated costs.

APPENDIX III

ANALYSIS OF NIGHT SET-BACK THERMOSTAT EFFECTS AND INSULATED SHUTTER OPERATION.

We are looking for an effective interior temperature (T_i) that can be used with the mean daily atmospheric temperature (T_a) to calculate the heat loss from a house in a 24-hour period.

ie. 24-hour heat loss = $(T_i - T_a) \times 24 \times G$ 1.

where G is the heat loss coefficient of the house.

We assume that the night set-back is deployed for 'h' hours in the 24-hour period. The interior temperature during the night set-back period is denoted by T_{is}. The mean atmospheric temperature during this period is denoted by T_{as}.

The house is in normal operation (without set-back) for a period (24 - h) hours in the 24-hour period. During this normal operation the house interior temperature is designated by T_{in} and the mean atmospheric temperature is designated by T_{an}.

Heat loss in set-back period = $(T_{is} - T_{as}) \times h \times G$ 2.

Heat loss in normal period = $(T_{in} - T_{an}) \times (24 - h) \times G$ 3.

Combining the three equations:

$$24 \times (T_i - T_a) = h \times (T_{is} - T_{as}) + (24 - h) \times (T_{in} - T_{an}) \quad 4.$$

Looking at atmospheric temperatures only, it is clear that:

$$24 \times T_a = h \times T_{as} + (24 - h) \times T_{an} \qquad 5.$$

From equations 4 and 5:

$$24 \times T_i = h \times T_{is} + (24 - h) \times T_{in} \qquad 6.$$

From which:

$$T_i = f \times T_{is} + (1 - f) \times T_{in} \qquad 7.$$

where 'f' is the fraction of the day in which the set-back is deployed.

This is an interesting result; it shows that the effective interior house temperature is determined solely by the thermostat settings and is not affected by any atmospheric loading effects. In short, it means that it does not matter if the set-back is employed at night or during the day, provided the duration and level of the set-back is fixed.

We now consider the effect of window shutters, and assume that these are deployed on the same schedule as the night set-back thermostat. Then:

$$24 \times G_m \times (T_i - T_a) = h \times G_s \times (T_{is} - T_{as}) + (24 - h) \times G_n \times (T_{in} - T_{an}) \qquad 8.$$

where: G_m is the effective mean heat loss coefficient
G_s is the heat loss coefficient with the shutters closed
G_n is the heat loss coefficient in normal daytime operation.

Therefore:

$$G_m = \frac{f \times G_s \times (T_{is} - T_{as}) + (1 - f) \times G_n \times (T_{in} - T_{an})}{(T_i - T_a)} \quad 9.$$

G_s and G_n can be calculated from the input data, h can be assumed to be about 8 hours, T_{is} is the night set-back temperature, T_{in} is the normal house temperature during the day and T_i is the weighted average of the two thermostat settings, as given by equation 7.

For a reasonable approximation it can be assumed that T_a is the monthly mean temperature, T_{as} is the monthly mean-minimum temperature, and T_{an} is the monthly mean-maximum temperature - all taken from AES records.

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